[0056] The features described herein may be embodied in different forms, and are not to be construed as being limited to the examples described herein. Rather, the examples described herein have been provided so that this disclosure will be thorough and complete, and will convey the full scope of the disclosure to one of ordinary skill in the art.

[0057] Hereinafter, reference will now be made in detail to examples with reference to the accompanying drawings, wherein like reference numerals refer to like elements throughout.

[0058] Various alterations and modifications may be made to the examples. Here, the examples are not construed as limited to the disclosure and should be understood to include all changes, equivalents, and replacements within the technical scope of the disclosure.

[0059] The terminology used herein is for the purpose of describing particular examples only and is not to be limiting of the examples. As used herein, the singular forms "a", "an", and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "include/comprise" and/or "have" when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components, and/or combinations thereof, but do not preclude the presence or addition of one or more other features, numbers, steps, operations, elements, components, and/or groups thereof.

[0060] Unless otherwise defined, all terms including technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which examples belong. It will be further understood that terms, such as those defined in commonly-used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0061] When describing the examples with reference to the accompanying drawings, like reference numerals refer to like constituent elements and a repeated description related thereto will be omitted. When it is determined detailed description related to a related known function or configuration they may make the purpose of the examples unnecessarily ambiguous in describing the examples, the detailed description will be omitted here.

[0062] FIG. **1** illustrates a process of generating caustics by light incident on a first object in accordance with one or more embodiments.

[0063] Referring to FIG. **1**, a caustic effect appears on a bottom surface when light incident on the first object, for example, water is refracted.

[0064] Rays **120** of light emitted from a light source **110** reach a water surface **130** in a direction indicated by a solid arrow. The rays **120** are refracted by water and/or reflected from the water along a surface normal **150** of the water surface **130**. Refracted or reflected rays **140** meet a bottom surface **160** that is a neighboring object. A point at which each of the refracted or reflected rays **140** meets or collides with the bottom surface **160** is referred to as an "intersection position" **170**. When a large number of intersection positions **170** are generated, reticulated light patterns, that is, caustics are generated on the bottom surface **160**.

[0065] FIG. **2** illustrates a method of expressing caustics in accordance with one or more embodiments.

[0066] Referring to FIG. **2**, in operation **210**, an expression apparatus in accordance with one or more embodiments calculates intersection positions at which rays emitted from a light source pass through particles of a first object and meet a second object. The first object is a transparent or semi-transparent object. The first object includes, for example, a fluid, for example, water, water vapor, a solid, for example, a glass, or an elastic body with an elasticity, for example, a transparent rubber ball. The first object has transparent or semitransparent properties allowing the rays to be reflected and refracted by passing through the first object. The first object may be modeled, for example, by particles of various sizes. An example of the first object modeled by particles is described with reference to FIG. **5**.

[0067] The second object with which rays collide is an opaque object. The second object is, for example, a bottom surface or an obstacle located in water, clouds, or other transparent or semitransparent medium.

[0068] Operation **210** is performed to determine a caustic expression position, and the expression apparatus traces a path of the rays and calculates the intersection positions for each of the particles. The intersection positions for each of the particles are calculated using a any suitable refraction equation. An example of a scheme by which the expression apparatus of one or more embodiments calculates to determine intersection positions of the ray with the particles is described with reference to FIG. **4**.

[0069] Prior to calculating of the intersection positions, the expression apparatus receives scene information, for example, a position of the light source, a depth map pre-rendered from the position of the light source, positions of the particles, and a surface normal vector of the first object (or the particles). The expression apparatus calculates the intersection positions for each of the particles based on the received information.

[0070] The expression apparatus determines particles directly visible from the light source among the particles, and calculates intersection positions for the particles directly visible from the light source. The particles directly visible from the light source are, for example, surface particles of a surface of the first object, or surface particles of the first object that are not covered or occluded by an obstacle.

[0071] The expression apparatus calculates intersection positions corresponding to points at which the rays reach an object by passing through the particles directly visible from the light source. A scheme, according to one or more embodiments, of determining particles directly visible from the light source is described with reference to FIG. **6**.

[0072] In operation **220**, the expression apparatus applies caustic textures to the intersection positions calculated in operation **210**. The expression apparatus marks vertices corresponding to the intersection positions on a bottom surface, and applies the caustic textures to the vertices. Examples of caustic textures are described with reference to FIG. **9**.

[0073] The expression apparatus uses caustic textures which may be stored in advance in correspondence to the particles without a change, or the textures may be modified such as by, for example, connections, interpolations, extrapolations, and the like, in real time. Such stored caustic textures, based on an external force exerted on the first object, to transformatively apply the caustic textures to the vertices in light of the external force.